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DESCRIPTION

IMAGE MATCHING SYSTEM USING THREE-DIMENSIONAL OBJECT MODEL, IMAGE MATCHING METHOD, AND IMAGE MATCHING PROGRAM

TECHNICAL FIELD

The present invention relates to an image matching system using a three-dimensional object model, an image matching method, and an image matching program. In particular, the present invention relates to an image matching system capable of retrieving a reference image stored in a database (DB) on the basis of an input image of an object (human face) picked up under a different pose and illumination condition, and its image matching method and image matching program.

BACKGROUND ART

An example of a conventional image matching system is described in Tsutada etc., "Dictionary configuration method for discriminating person independently of face direction," The Transactions of the Institute of Electronics, Information and Communication Engineers, D-II, Vol. J78-D-II, No. 11 (1995), pp. 1639-1649 (hereafter referred to as first conventional technique). As shown in FIG. 26, an image matching system according to the first image matching system includes an image input section 10, an image matching section 40, a result display section 80, a reference image storage section 70, and a reference image registration section 75.

The conventional image matching system having such a configuration operates as hereafter described.

Reference images of various objects (such as reference face images of persons) picked up are previously stored in the reference image storage section 70 by the reference image registration section 75. However,

reference images greatly change depending on the condition at the time of imaging (conditions such as the pose and illumination). With respect to one object, therefore, a plurality of (a large number of) images imaged under various conditions are previously stored.

The image input section 10 is implemented by using, for example, a camera. The imaged input image is stored in a memory (not illustrated). The image matching section 40 compares the input image obtained from the image input section 10 with each of reference images obtained from the reference image storage section 70, calculates similarities (or distance values) of respective features, and selects a reference image having the greatest similarity (or the shortest distance) for each object. Each image is represented by gray level features. In the calculation of similarity between features and the calculation of the distance value, for example, the normalized correlation and Euclidean distance are used. The result display section 80 displays a reference image of an object having the greatest similarity selected from among the reference images, as a matching result (or displays candidate reference images in the descending order of the similarity).

Another example of a conventional image matching system is described in Japanese Patent Application Laid-Open No. 2000-322577 (hereafter referred to as second conventional technique). As shown in FIG. 28, the conventional image matching system includes an image input section 10, an image conversion section 35, a partial image matching section 45, a result display section 80, a reference image registration section 75, a representative three-dimensional object model storage section 20, and a three-dimensional object model registration section 25.

The conventional image matching system having such a configuration operates as hereafter described.

One or more representative three-dimensional object models obtained from the three-dimensional object model registration section 25 are previously stored in the representative three-dimensional object model storage section 20. As regards a partial region common to the input image obtained from the image input section 10 and each of the reference image obtained from the reference image storage section 70, the image conversion section 35 converts the input image and/or the reference image so as to make the input condition (such as the pose condition) the same by using a three-dimensional object model obtained from the representative three-dimensional object model storage section 20, and thereby generates partial images.

For example, as shown in FIG. 29, the partial region is a feature portion such as an eye, a nose or a mouth. By previously specifying a feature point with respect to each of the images and the three-dimensional object models, correspondence can be taken. The partial image matching section 45 compares the converted input image obtained from the image conversion section 35 with a partial image of each of the reference images, calculates respective average similarities, and selects a reference image having the greatest similarity for each object. The result display section 80 displays an object having the greatest similarity among the reference images, as a matching result.

DISCLOSURE OF INVENTION

The above-described conventional techniques have various problems described hereafter.

First, the above-described first and second conventional techniques have a problem that a large number of reference images of an object to be registered, picked up under various conditions become necessary.

The reason is as follows: the input image is directly compared with a reference image; if the input image pickup condition is not restricted, therefore, it is necessary to previously prepare reference images that are close to the input image in pickup condition in order to cope with a large number of pose and illumination conditions. As a matter of fact, however, there are infinite possibilities in the pose and illumination conditions, and it is practically impossible to previously prepare a large number of images associated with various conditions.

Secondly, in the second conventional technique, the input image or the reference image is converted so as to square them with each other in pose, and comparison is conducted. If the number of the reference images of a three-dimensional object model is not sufficient or the pose is largely different, therefore, distortion caused by the conversion becomes large and matching cannot be conducted correctly, resulting in a problem. There is also a problem that it is very difficult to square the illumination conditions with each other by conducting conversion and a common region certainly needs to be present because images are compared in the common region.

Thirdly, the conventional techniques have a problem that it takes a considerably long time to conduct matching.

The reason is as follows: in the conventional techniques, the input image is compared with a plurality of reference images of respective objects; if the number of objects is M and the number of reference images of each object is L, therefore, image comparison must be conducted at least L□ M times.

An object of the present invention is to provide an image matching system, an image matching method, and an image matching program that make it possible to retrieve a reference image registered in a database on the basis of an input image as regards images picked under different pose and illumination conditions every object, even when only a small number of reference images are available.

Another object of the present invention is to provide an image matching system, an image matching method, and an image matching program that make it possible to conduct matching with a small number of reference images of three-dimensional object models without conducting processing such as converting the input image or the reference image so as to make the pose coincide and that makes it possible to conduct matching even if a region common to the images is not present.

Another object of the present invention is to provide an image matching system, an image matching method, and an image matching program that make it possible to conduct image matching without always generating a certain necessary number of three-dimensional objects with respect to all objects.

Still another object of the present invention is to provide an image matching system, an image matching method, an image matching program that make it possible to conduct retrieval at high speed even when a database has reference images concerning a large number of objects registered therein.

The present invention provides an image matching system for retrieving a reference image similar to an input image, the image matching system including means for making a match between the input image and a plurality of representative three-dimensional object models, means for

making a match between the reference image and the representative three-dimensional object models, and means for retrieving the reference image similar to the input image by using a result of the match between the input image and the representative three-dimensional object models and a result of the match between the reference image and the representative three-dimensional object models.

The image matching system may further include means for finding a reference three-dimensional object model associated with the reference image similar to the input image, and means for newly retrieving the reference image similar to the input image by using the reference three-dimensional object model and the input image.

The image matching system may further include means for finding a reference three-dimensional object model associated with the reference image similar to the input image, conversion means for squaring an input condition of the input image with that of the reference image by converting the input image and/or the reference image on the basis of the reference three-dimensional object model, and means for retrieving the reference image associated with the input image by making a match between the input image and reference image squared in input condition.

In the image matching system, the conversion means may previously convert the reference image, and square an input condition of the input image with that of the reference image.

The image matching system may include image input means for inputting the input image, a representative three-dimensional object model storage section for storing a plurality of representative three-dimensional object models, image generation means for generating at least one comparison image close in input condition to the input image every

representative three-dimensional object model on the basis of the representative three-dimensional object models stored in the representative three-dimensional object model storage section, image matching means for calculating a similarity between the input image and each of the comparison images generated by the image generation means, selecting a maximum similarity with respect to comparison images associated with each representative three-dimensional object model, and regarding the maximum similarity as a similarity between the input image and the representative three-dimensional object model, a reference image storage section for storing the reference images of objects, a reference image matching result storage section for storing similarities between the reference images stored in the reference image storage section and representative three-dimensional object models stored in the representative three-dimensional object model storage section, and result matching means for extracting the reference image similar to the input image on the basis of similarities between the input image and the representative three-dimensional object models calculated by the image matching means and similarities between the reference images and the representative three-dimensional object models stored in the reference image matching result storage section.

The image matching system may further include three-dimensional object model registration means for registering representative three-dimensional object models in the representative three-dimensional object model storage section, reference image registration means for registering reference images in the reference image storage section, and reference image matching result update means for conducting calculation of the similarities using the image matching means, on a combination of a reference image and a representative three-dimensional object model newly

generated by registration, when a new representative three-dimensional object model is registered in the representative three-dimensional object model storage section by the three-dimensional object model registration means, or when a new reference image is registered in the reference image storage section by the reference image registration means, and adding a result of the calculation to results in the reference image matching result storage section.

In the image matching system, the image matching means may calculate a similarity between the input image and a representative three-dimensional object model every partial region, the reference image matching result storage section may store similarities between the reference images stored in the reference image storage section and representative three-dimensional object models stored in the representative three-dimensional object model storage section, every partial region, and the result matching means may extract the reference image similar to the input image on the basis of similarities between the input image and the representative three-dimensional object models calculated by the image matching means every partial region and similarities between the reference images and the representative three-dimensional object models, stored in the reference image matching result storage section every partial region.

In the image matching system, the result matching means may calculate similarities between similarities between the input image and the representative three-dimensional object models and similarities between the reference images and the representative three-dimensional object models, and in the calculation provide the resultant similarities with weights on the basis of candidate precedence of similarities between the input image and

the comparison images and the representative three-dimensional object models.

The image matching system may include image input means for inputting the input image, a representative three-dimensional object model storage section for storing a plurality of representative three-dimensional object models, image generation means for generating at least one comparison image close in input condition to the input image every representative three-dimensional object model on the basis of the representative three-dimensional object models stored in the representative three-dimensional object model storage section, image matching means for calculating a similarity between the input image and each of the comparison images generated by the image generation means, selecting a maximum similarity with respect to comparison images associated with each representative three-dimensional object model, and regarding the maximum similarity as a similarity between the input image and the representative three-dimensional object model, a reference image storage section for storing the reference images of objects, a reference image matching result storage section for storing similarities between the reference images stored in the reference image storage section and representative three-dimensional object models stored in the representative three-dimensional object model storage section, result matching means for extracting the reference image similar to the input image on the basis of similarities between the input image and the representative three-dimensional object models calculated by the image matching means and similarities between the reference images and the representative three-dimensional object models stored in the reference image matching result storage section, a reference three-dimensional object model storage section for storing reference three-

dimensional object models associated with the reference images stored in the reference image storage section, second image generation means for obtaining reference three-dimensional object models associated with reference images extracted from the result matching means, from the reference three-dimensional object model storage section, and generating at least one second comparison image close in input condition to the input image every reference three-dimensional object model on the basis of the obtained reference three-dimensional object models, and second image matching means for calculating similarities between the input image and second comparison images generated by the second image generation means, selecting a maximum similarity from among second comparison images associated with each of the reference three-dimensional object models, and regarding the maximum similarity as a similarity between the input image and the reference three-dimensional object model.

The image matching may further include three-dimensional object model registration means for registering representative three-dimensional object models in the representative three-dimensional object model storage section, reference image registration means for registering reference images in the reference image storage section, and reference image matching result update means for conducting calculation of the similarities using the image matching means, on a combination of a reference image and a representative three-dimensional object model newly generated by registration, when a new representative three-dimensional object model is registered in the representative three-dimensional object model storage section by the three-dimensional object model registration means, or when a new reference image is registered in the reference image storage section by the reference image registration means, and adding a result of the

calculation to results in the reference image matching result storage section, and three-dimensional object model generation means responsive to registration of a similarity between the reference image and the representative three-dimensional object model in the reference image matching result storage section conducted by the reference image matching result update means, for generating the reference three-dimensional object model associated with the reference image by combining the representative three-dimensional object models stored in the representative three-dimensional object model storage section on the basis of the similarity, and registering the generated reference three-dimensional object model in the reference three-dimensional object model storage section.

In the image matching system, the three-dimensional object model generation means may generate a reference three-dimensional object model associated with each reference image by combining representative three-dimensional object models stored in the representative three-dimensional object model storage section every partial region, on the basis of similarities obtained every partial region between reference images stored in the reference image storage section and representative three-dimensional object models stored in the representative three-dimensional object model storage section, and register the generated reference three-dimensional object model in the reference three-dimensional object model storage section.

In the image matching system, the image matching means may calculate a similarity between the input image and a representative three-dimensional object model every partial region, the reference image matching result storage section may store similarities between the reference images stored in the reference image storage section and representative three-dimensional object models stored in the representative three-dimensional

object model storage section, every partial region, and the result matching means may extract the reference image similar to the input image on the basis of similarities between the input image and the representative three-dimensional object models calculated by the image matching means every partial region and similarities between the reference images and the representative three-dimensional object models, stored in the reference image matching result storage section every partial region.

In the image matching system, the result matching means may calculate similarities between similarities between the input image and the representative three-dimensional object models and similarities between the reference images and the representative three-dimensional object models, and in the calculation, provide the resultant similarities with weights on the basis of candidate precedence of similarities between the input image and the comparison images and the representative three-dimensional object models.

The image matching system may include image input means for inputting the input image, a representative three-dimensional object model storage section for storing a plurality of representative three-dimensional object models, image generation means for generating at least one comparison image close in input condition to the input image every representative three-dimensional object model on the basis of the representative three-dimensional object models stored in the representative three-dimensional object model storage section, image matching means for calculating a similarity between the input image and each of the comparison images generated by the image generation means, selecting a maximum similarity with respect to comparison images associated with each representative three-dimensional object model, and regarding the maximum

similarity as a similarity between the input image and the representative three-dimensional object model, a reference image storage section for storing the reference images of objects, a reference image matching result storage section for storing similarities between the reference images stored in the reference image storage section and representative three-dimensional object models stored in the representative three-dimensional object model storage section, result matching means for extracting the reference image similar to the input image on the basis of similarities between the input image and the representative three-dimensional object models calculated by the image matching means and similarities between the reference images and the representative three-dimensional object models stored in the reference image matching result storage section, a reference three-dimensional object model storage section for storing reference three-dimensional object models associated with the reference images stored in the reference image storage section, image conversion means for obtaining reference three-dimensional object models associated with reference images extracted from the result matching means, from the reference three-dimensional object model storage section, squaring an input condition of the input image with that of the reference image extracted by the result matching means by converting the input image and/or the reference image extracted by the result matching means, on the basis of the obtained reference three-dimensional object models, and generating partial images respectively of the input image and the reference image squared in input condition with each other, and partial image matching means for calculating a similarity between the partial image of the input image and the partial image of the reference image generated by the image conversion means.

The image matching system may further include three-dimensional object model registration means for registering representative three-dimensional object models in the representative three-dimensional object model storage section, reference image registration means for registering reference images in the reference image storage section, and reference image matching result update means for conducting calculation of the similarities using the image matching means, on a combination of a reference image and a representative three-dimensional object model newly generated by registration, when a new representative three-dimensional object model is registered in the representative three-dimensional object model storage section by the three-dimensional object model registration means, or when a reference image is registered in the reference image storage section by the reference image registration means, and adding a result of the calculation to results in the reference image matching result storage section, and three-dimensional object model generation means responsive to registration of a similarity between the reference image and the representative three-dimensional object model in the reference image matching result storage section conducted by the reference image matching result update means, for generating the reference three-dimensional object model associated with the reference image by combining the representative three-dimensional object models stored in the representative three-dimensional object model storage section on the basis of the similarity, and registering the generated reference three-dimensional object model in the reference three-dimensional object model storage section.

In the image matching system, the three-dimensional object model generation means may generate a reference three-dimensional object model associated with each reference image by combining representative three-

dimensional object models stored in the representative three-dimensional object model storage section every partial region, on the basis of similarities obtained every partial region between reference images stored in the reference image storage section and representative three-dimensional object models stored in the representative three-dimensional object model storage section, and register the generated reference three-dimensional object model in the reference three-dimensional object model storage section.

In the image matching system, the image matching means may calculate a similarity between the input image and a representative three-dimensional object model every partial region, the reference image matching result storage section may store similarities between the reference images stored in the reference image storage section and representative three-dimensional object models stored in the representative three-dimensional object model storage section, every partial region, and the result matching means may extract the reference image similar to the input image on the basis of similarities between the input image and the representative three-dimensional object models calculated by the image matching means every partial region and similarities between the reference images and the representative three-dimensional object models, stored in the reference image matching result storage section every partial region.

In the image matching system, the result matching means may calculate similarities between similarities between the input image and the representative three-dimensional object models and similarities between the reference images and the representative three-dimensional object models, and in the calculation, provide the resultant similarities with weights on the basis of candidate precedence of similarities between the input image and

the comparison images and the representative three-dimensional object models.

In the image matching system, the object may be a human face.

According to the present invention, effects described hereafter are achieved.

A first effect will now be described. With respect to an input image of an object picked up under a different input condition such as a different pose and illumination condition a reference image of the same object can be retrieved, even if only one reference image or a small number of reference images are present. Furthermore, matching can be conducted with a small number of reference images of three-dimensional object models, without conducting processing such as converting the input image or the reference image so as to make their poses coincide with each other. In addition, matching can be conducted even if a region common to the images is not present. Furthermore, image matching becomes possible without always generating a predetermined number of three-dimensional object models for every object.

The reason is that a reference image is retrieved by comparing a result of matching between the input image and representative three-dimensional object models with a result of matching between reference images and representative three-dimensional object models. The reason is also that a reference three-dimensional object model is generated by combining representative three-dimensional object models and subjected to matching.

A second effect is that a reference image can be retrieved at high speed with respect to an input image.

The reason is that matching of representative three-dimensional object models less than the objects is conducted and image matching is conducted by using the calculation of similarity of the matching result. Even when conducting matching with a reference three-dimensional object model, reference images having high similarity are extracted by using representative three-dimensional object models, and then matching of high precedence candidates with reference three-dimensional object models is conducted.

BRIEF DESCRIPTION OF DRAWINGS

FIG. 1 is a block diagram showing a configuration of an image matching system according to a first embodiment of the present invention;

FIG. 2 is a flow char showing operation conducted at the time of matching in a first embodiment;

FIG. 3 is a diagram showing a concrete example of a representative three-dimensional object model in a first embodiment;

FIG. 4 is a diagram showing concrete examples of a reference image in a first embodiment;

FIG. 5 is a diagram showing a concrete example of a reference image matching result in a first embodiment;

FIG. 6 is a diagram showing a concrete example of an input image in a first embodiment;

FIG. 7 is a diagram showing a concrete example of an input image matching result in a first embodiment;

FIG. 8 is a diagram showing a concrete example of result matching in a first embodiment;

FIG. 9 is a block diagram showing a configuration of an image matching system according to a second embodiment of the present invention;

FIG. 10 is a flow chart showing operation conducted at the time of three-dimensional object model registration in a second embodiment;

FIG. 11 is a flow chart showing operation conducted at the time of reference image registration in a second embodiment;

FIG. 12 is a diagram showing a concrete example of a matching result of a three-dimensional object model registered in a second embodiment;

FIG. 13 is a diagram showing a concrete example of update of a reference image matching result in a second embodiment;

FIG. 14 is a diagram showing a concrete example of a matching result of a registered reference image in a second embodiment;

FIG. 15 is a diagram showing a concrete example of update of a reference image matching result in a second embodiment;

FIG. 16 is a block diagram showing a configuration of an image matching system according to a third embodiment of the present invention;

FIG. 17 is a flow chart showing operation conducted at the time of matching in a third embodiment;

FIG. 18 is a diagram showing concrete examples of a reference three-dimensional object model in a third embodiment;

FIG. 19 is a diagram showing a concrete example of a reference image matching result in a third embodiment;

FIG. 20 is a block diagram showing a configuration of an image matching system according to a fourth embodiment of the present invention;

FIG. 21 is a flow chart showing operation conducted at the time of three-dimensional object model registration in a fourth embodiment;

FIG. 22 is a flow chart showing operation conducted at the time of reference image registration in a fourth embodiment;

FIG. 23 is a block diagram showing a configuration of an image matching system according to a fifth embodiment of the present invention;

FIG. 24 is a flow chart showing operation conducted at the time of matching in a fifth embodiment;

FIG. 25 is a block diagram showing a configuration of an image matching system according to a sixth embodiment of the present invention;

FIG. 26 is a block diagram showing a configuration of an image matching system according to a first conventional technique;

FIG. 27 is a diagram showing a concrete example of coordinates of a three-dimensional object model;

FIG. 28 is a block diagram showing a configuration of an image matching system according to a second conventional technique; and

FIG. 29 is a diagram showing a concrete example of a partial region of a second conventional technique.

BEST MODE FOR CARRYING OUT THE INVENTION

Hereafter, embodiments of the present invention will be described in detail with reference to the drawings.

With reference to FIG. 1, an image matching system according to a first embodiment of the present invention includes an image input section 10, an image generation section 30, an image matching section 40, a result matching section 60, a result display section 80, a reference image storage section 70, a representative three-dimensional object model storage section 20, and a reference image matching result storage section 50.

Representative three-dimensional object models (three-dimensional shapes of objects and textures on object surfaces) are previously registered in the representative three-dimensional object model storage section 20. The three-dimensional object models can be generated by using, for example, a three-dimensional shape measurement apparatus described in Japanese Patent Application Laid-Open No. 2001-12925 or an apparatus that reconstructs a three-dimensional shape from a plurality of images picked up with a large number of cameras and that is described in Japanese Patent Application Laid-Open No. 9-91436.

As shown in FIG. 27, the three-dimensional object model has a shape $P_Q(x, y, z)$ and a texture $T_Q(R, G, B)$ in a three-dimensional space (x, y, z) at an object surface, as information. Q represents an index of a point on the object surface, and corresponds to coordinates of a point Q(s,t) obtained by projecting a point on the object surface onto a sphere centering around the center of gravity of the object from the center of gravity. For the purpose of matching, CG images for learning under various illumination conditions are previously generated by using three-dimensional object models and computer graphics, and a basic image group is derived by conducting principal component analysis on the CG images for learning.

The image generation section 30 generates a plurality of comparison images close in illumination condition to an input image obtained from the image input section 10, while supposing a pose condition on the basis of a representative three-dimensional object model obtained from the representative three-dimensional object model storage section 20. Here, the generation of the comparison image close in illumination condition to the input image can be implemented by conducting coordinate conversion on a basic image group obtained beforehand on the basis of the supposed pose

condition and obtaining coefficients of a linear sum by using the least square method so as to make the linear sum of the basic images subjected to the coordinate conversion close to the input image.

A technique for generating a comparison image close to the input image from the three-dimensional object model is described in, for example, "Face matching using automatic correction of both illumination condition and pose," Technical Report of the Institute of Electronics, Information and Communication Engineers, Vol. 101, No. 524, PRMU2001-153~175 (2001), pp. 59-64.

The image matching section 40 estimates the pose by comparing the input image obtained from the image input section 10 with each of comparison images obtained from the image generation section 30, calculating a similarity between the input image and each of the comparison images, and selecting a comparison image having the greatest similarity for each object.

The image generation section 30 and the image matching section 40 handles each of the reference images stored in the reference image storage section 70 serving as a database (DB) that stores reference images as the input image and matches representative three-dimensional object models stored in the representative three-dimensional object model storage section 20 with each of the reference images. Results obtained by the matching are previously stored in the reference image matching result storage section 50.

The result matching section 60 compares a result of matching of the input image obtained from the image input section 10 conducted by the image generation section 30 and the image matching section 40 with the matching result of each reference image in the reference image matching result storage section 50, and extracts reference images having similar

matching results, in the descending order of the similarity. The result display section 80 displays an object having the greatest similarity as a matching result.

Reference images which are two-dimensional images of an object to be retrieved are registered in the reference image storage section 70. As for the reference images, there are no restrictions to the input condition including the illumination and pose. At least one image is registered every object (retrieval subject).

A plurality of representative three-dimensional object models are stored in the representative three-dimensional object model storage section 20.

General operation of the first embodiment will now be described in detail with reference to FIG. 1 and a flow chart shown in FIG. 2.

At the time of input image matching, an input image is first obtained by the input image section 10 (step 100 in FIG. 2). Subsequently, the image generation section 30 generates comparison images that are close in the input condition such as the pose and illumination to the input image, i.e., comparison images that facilitate comparison, with respect to each of the representative three-dimensional object models stored in the representative three-dimensional object model storage section 20 (step 101).

The image matching section 40 finds similarity between the input image and each of the comparison images (step 102). The result matching section 60 calculates a similarity between the matching result and a matching result of each of the reference image stored in the reference image matching result storage section 50, and extracts reference images having similar matching results, in the descending order of the similarity (step 103). Finally, a reference image having high similarity is displayed (step 104).

Effects of the first embodiment which has the configuration and which operates as described above will now be described.

The first embodiment has the configuration in which reference images are retrieved by comparing a result of matching between the input image and the representative three-dimensional object models with a result of matching between reference images and the representative three-dimensional object models. Even when only one reference image or a small number of reference images are present every object, therefore, reference images can be retrieved with respect to an input image of an object picked up under a different condition concerning the pose and illumination.

The present embodiment has a configuration in which image matching is conducted by conducting matching with representative three-dimensional object models which are less than objects and conducting similarity calculation on the results of the matching. This makes fast retrieval possible. Since the time taken for the similarity calculation of matching results is shorter than the time taken for the image matching, the retrieval time depends on the number of image matching operations. For example, if the number N of the representative three-dimensional object models is $N = M/100$ where M is the number of objects (the number of reference images), then the number of required image matching operations is $L \times N = L \times M/100$ where L is the number of comparison images for each representative three-dimensional object model generated in the image generation section 30. Thus, retrieval can be conducted with the number of times of matching as small as 1/100 of that in the conventional technique.

Operation of the first embodiment will now be described with reference to FIGS. 3 to 8 which show concrete embodiments.

As shown in FIG. 3, N representative three-dimensional object models C_j ($j = 1, 2, \ldots, N$) are stored in the representative three-dimensional object model storage section 20. As shown in FIG. 4, M reference images R_i ($i = 1, 2, \ldots, M$) respectively of the objects are stored in the reference image storage section 70 (A plurality of reference images may be present for each of the objects. In the ensuing description, however, it is supposed that one reference image is stored every object).

As shown in FIG. 5, a result (similarity S_{ij}) of matching of each of the reference images R_i with the representative three-dimensional object model C_j is stored in the reference image matching result storage section 50 by processing at the time of reference image registration. (In FIG. 5, the matching results are shown in the descending order of the similarity. As a matter of fact, however, the matching results may be stored in the order of model.)

It is supposed that an input image $I(u, v)$ as shown in FIG. 6 is obtained by the image input section 10 at the time of matching of the input image (step 100 in FIG. 2). Subsequently, the image generation section 30 generates L comparison images $G_{jk}(u, v)$ ($j = 1, \ldots, N$, $k = 1, \ldots, L$) which are close in input condition such as the pose and illumination to the input image, with respect to each of the representative three-dimensional object models C_j ($j = 1, \ldots, N$) in the representative three-dimensional object model storage section 20 (step 101).

In addition, the image matching section 40 finds a similarity $S(I, G_{jk})$ between the input image $I(u, v)$ and each of the comparison images $G_{jk}(u, v)$, and finds a maximum similarity $S_{0j} = \max_k S(I, G_{jk})$ every representative three-dimensional object model (step 102). The matching results (similarities) S_{0j} become, for example, as shown in FIG. 7.

The result matching section 60 calculates a similarity $D_i = D(S_{0j}, S_{ij})$ between the matching result S_{0j} and the matching result S_{ij} of each of the reference images in the reference image matching result storage section 50, and extracts reference images in the descending order of the similarity D_i of the matching result (step 103). The result of the extraction becomes, for example, as shown in FIG. 8. As reference images having a high possibility of being an image of the same object as the input image, R_1, R_5 and R_2 are obtained in the cited order. Finally, the reference images having high similarities are displayed (step 104).

As the calculation method of the similarity $D_i(S_{0j}, S_{ij})$ of the matching result, normalized correlation, rank_correlation, or the like can be used. The rank correlation is correlation of candidate precedence of the matching result. Denoting the candidate precedence of the matching result S_{0j} of the input image by A_{0j}, it follows that $A_{0,2} = 1$, $A_{0.6} = 2$ and $A_{0,3} = 3$ in the case of the matching result shown in FIG. 7. Denoting candidate precedence of the matching result S_{ij} of each of the reference images by A_{ij}, for example, the Spearman's rank correlation can be obtained according to the expression $1 - 6\Sigma_j(A_{0j}-A_{ij})^2/\{N(N^2-1)\}$.

In the similarity calculation, the similarities may be calculated after conducting variable conversion on the variables (such as S_{0j}, S_{ij} and A_{0j}, A_{ij}). The similarities may be calculated by weighting variables with weights $g(A_{0j}, A_{ij})$ based on the candidate precedence A_{0j} and/or A_{ij}. For example, specific gravities of high precedence candidates become great by setting $g(A_{0j}, A_{ij}) = 1/(A_{0j}+A_{ij})$ and replacing the similarities S_{0j} and S_{ij} respectively by $S_{0j}/(A_{0j}+A_{ij})$ and $S_{ij}/(A_{0j}+A_{ij})$. The similarities may be calculated with low precedence candidates excluded.

An image matching system according to a second embodiment of the present invention will now be described with reference to FIGS. 9 to 15. An image matching system according to the second embodiment of the present invention includes an image input section 10, an image generation section 30, an image matching section 40, a result matching section 60, a result display section 80, a reference image storage section 70, a reference image registration section 75, a representative three-dimensional object model storage section 20, a three-dimensional object model registration section 25, a reference image matching result storage section 50, and a reference image matching result update section 55. This configuration is obtained by adding the reference image registration section 75, the three-dimensional object model registration section 25, and the reference image matching result update section 55 to the configuration of the first embodiment.

As to components in the image matching system according to the second embodiment that are the same as those in the first embodiment, description will be omitted. The components added in the present embodiment will be described.

The three-dimensional object model registration section 25 registers a new representative three-dimensional object model (a three-dimensional shape of an object and a texture on the object surface) in the representative three-dimensional object model storage section 20.

When at the time of registration a representative three-dimensional object model is registered in the representative three-dimensional object model storage section 20 by the three-dimensional object model 25, and when a reference image is registered in the reference image storage section 70 by the reference image registration section 75, the reference image matching result update section 55 conducts matching operation on a

combination of a new reference image and a representative three-dimensional object model by using the image generation section 30 and the image matching section 40, and adds a result of the matching to data in the reference image matching result storage section 50.

The reference image registration section 75 registers reference images which are two-dimensional images of an object to be retrieved, in the reference image storage section 70. As for the reference images, there are no restrictions to the input condition including the illumination and pose. At least one image is registered every object (retrieval subject).

By the way, the three-dimensional object model registration section 25 is the same as the three-dimensional object model registration section 25 in the second conventional technique shown in FIG. 28. Representative three-dimensional object models obtained from the three-dimensional object model registration section 25 are previously stored in the representative three-dimensional object model storage section 20.

General operation of the second embodiment will now be described in detail with reference to FIG. 9 and flow charts shown in FIGS. 2, 10 and 11.

Operation conducted at the time of matching of the input image is completely the same as the operation of the first embodiment shown in FIG. 2.

At the time of input image matching, an input image is first obtained by the input image section 10 (step 100 in FIG. 2). Subsequently, the image generation section 30 generates comparison images that are close in the input condition such as the pose and illumination to the input image, i.e., comparison images that facilitate comparison, with respect to each of

the representative three-dimensional object models stored in the representative three-dimensional object model storage section 20 (step 101).

The image matching section 40 finds a similarity between the input image and each of the comparison images (step 102). The result matching section 60 calculates a similarity between the matching result and the matching result of each of the reference images stored in the reference image matching result storage section 50, and extracts reference images having similar matching results, in the descending order of the similarity (step 103). Finally, a reference image having high similarity is displayed (step 104).

Operation conducted at the time of representative three-dimensional object model registration and operation conducted at the time of reference image registration will now be described.

At the time of representative three-dimensional object model (a three-dimensional shape of an object and a texture on the object surface) registration, the three-dimensional object model registration section 25 first registers a new representative three-dimensional object model in the representative three-dimensional object model storage section 20 (step 200 in FIG. 10).

Subsequently, the reference image matching result update section 55 sends each of the reference images stored in the reference image storage section 70 to the image input section 10 as the input image. The reference image matching result update section 55 conducts matching, in the image matching section 40, of each of the reference images with comparison images generated by the image generation section 30 on the basis of the registered representative three-dimensional object model, and finds a similarity (step 201). Finally, the reference image matching result update

section 55 adds a result of the matching to each of the matching results of the reference images stored in the reference image matching result storage section 50 (step 202).

At the time of reference image registration, the reference image registration section 75 first registers a new reference image in the reference image storage section 70 (step 210 in FIG. 11).

Subsequently, the reference image matching result update section 55 sends the reference image registered in the reference image storage section 70 to the image input section 10 as the input image. The reference image matching result update section 55 conducts matching, in the image matching section 40, of the reference image with comparison images generated by the image generation section 30 on the basis of the representative three-dimensional object model stored in the representative three-dimensional object model storage section 20, and finds similarities (step 211). Finally, the reference image matching result update section 55 adds a result of the matching to the reference image matching result storage section 50 (step 212).

Effects of the second embodiment which has the configuration and which operates as described above will now be described.

The second embodiment has the configuration in which reference images are retrieved by comparing a result of matching between the input image and the representative three-dimensional object models with a result of matching between reference images and the representative three-dimensional object models. Even when only one reference image or a small number of reference images are present every object, therefore, reference images can be retrieved with respect to an input image of an object picked up under a different condition concerning the pose and illumination.

The present embodiment has a configuration in which image matching is conducted by conducting matching with representative three-dimensional object models which are less than objects and conducting similarity calculation on the results of the matching. This makes fast retrieval possible. Since the time taken for the similarity calculation of matching results is shorter than the time taken for the image matching, the retrieval time depends on the number of image matching operations. For example, if the number N of the representative three-dimensional object models is $N = M/100$ where M is the number of objects (the number of reference images), then the number of required image matching operations is $L \times N = L \times M/100$ where L is the number of comparison images for each representative three-dimensional object model generated in the image generation section 30. Thus, retrieval can be conducted with the number of times of matching as small as 1/100 of that in the conventional technique.

Operation of the second embodiment will now be described with reference to concrete embodiments.

As shown in FIG. 3, N representative three-dimensional object models C_j ($j = 1, 2, \dots, N$) are stored in the representative three-dimensional object model storage section 20 in the same way as the first embodiment. As shown in FIG. 4, M reference images R_i ($i = 1, 2, \dots, M$) of the objects are stored in the reference image storage section 70. As shown in FIG. 5, a result (similarity S_{ij}) of matching of each reference image R_i with the representative three-dimensional object model C_j is stored in the reference image matching result storage section 50 by processing at the time of reference image registration.

It is supposed that an input image $I(u, v)$ as shown in FIG. 6 is obtained by the image input section 10 at the time of matching of the input

image (step 100 in FIG. 2). Subsequently, the image generation section 30 generates L comparison images $G_{jk}(u, v)$ ($j = 1, \ldots, N$, $k = 1, \ldots, L$) which are close in input condition such as the pose and illumination to the input image, with respect to each of the representative three-dimensional object models C_j ($j = 1, \ldots, N$) in the representative three-dimensional object model storage section 20 (step 101).

In addition, the image matching section 40 finds a similarity $S(I, G_{jk})$ between the input image $I(u, v)$ and each of the comparison images $G_{jk}(u, v)$, and finds a maximum similarity $S_{0j} = \max_k S(I, G_{jk})$ every representative three-dimensional object model (step 102). The matching results (similarities) S_{0j} become, for example, as shown in FIG. 7.

The result matching section 60 calculates similarities $D_i = D(S_{0j}, S_{ij})$ between the matching result S_{0j} and the matching results S_{ij} of the reference images in the reference image matching result storage section 50, and extracts reference images in the descending order of the similarity D_i of the matching result (step 103). The result of the extraction becomes, for example, as shown in FIG. 8. As reference images having a high possibility of being an image of the same object as the input image, R_1, R_5 and R_2 are obtained in the cited order. Finally, the reference images having high similarities are displayed (step 104).

At the time of representative three-dimensional object model registration, the three-dimensional object model registration section 25 first registers a new representative three-dimensional object model. If N=50 representative three-dimensional object models are already registered in the representative three-dimensional object model storage section 20, the three-dimensional object model registration section 25 registers a new fifty-first representative three-dimensional object model C_{51} (step 200 in FIG. 10).

Subsequently, the reference image matching result update section 55 sends each reference image R_i stored in the reference image storage section 70 to the image input section 10 as the input image. The reference image matching result update section 55 conducts matching of the each reference image R_i with the registered representative three-dimensional object model C_{51} by using the image generation section 30 and the image matching section 40, and finds each similarity $S_{i,51} = \max_k S(R_i, G_{51,k})$ (step 201).

The matching result (similarity) $S_{i,51}$ becomes, for example, as shown in FIG. 12. Finally, as shown in FIG. 13, the reference image matching result update section 55 adds the matching result to the matching results of each of the reference images stored in the reference image matching result storage section 50 (step 202).

At the time of reference image registration, the reference image registration section 75 first registers a new reference image in the reference image storage section 70. If M=100 reference images are already registered in the reference image storage section 70, the reference image registration section 75 registers a new hundred first reference image R_{101} in the reference image storage section 70 (step 210 in FIG. 11).

Subsequently, the reference image matching result update section 55 sends the reference image R_{101} registered in the reference image storage section 70 to the image input section 10 as the input image. The reference image matching result update section 55 conducts matching of the reference image R_{101} with each three-dimensional object model C_j stored in the representative three-dimensional object model storage section 20 by using the image generation section 30 and the image matching section 40, and finds each similarity $S_{101,j} = \max_k S(R_{101}, G_{jk})$ (step 211).

The matching result (similarity) becomes, for example, as shown in FIG. 14. Finally, the reference image matching result update section 55 adds the matching result to the reference image matching result storage section 50 (step 212).

An image matching system according to a third embodiment of the present invention will now be described in detail with reference to FIGS. 16 to 19.

With reference to FIG. 16, an image matching system according to the third embodiment of the present invention includes an image input section 10, an image generation section 30, an image matching section 40, a result matching section 60, a second image generation section 31, a second image matching section 41, a result display section 80, a reference image storage section 70, a representative three-dimensional object model storage section 20, a reference image matching result storage section 50, and a reference three-dimensional object model storage section 21.

These components nearly operate as described below. The image input section 10, the image generation section 30, the image matching section 40, the result matching section 60, the result display section 80, the reference image storage section 70, and the representative three-dimensional object model storage section 20 conduct the same processing as the processing conducted in the first embodiment of the present invention shown in FIG. 1.

Reference three-dimensional object models associated with the reference image are previously stored in the reference three-dimensional object model storage section 21. The reference three-dimensional object models can be generated by combining representative three-dimensional object models stored in the representative three-dimensional object model

storage section 20 on the basis of information concerning the reference image matching result registered in the reference image matching result storage section 50. Or if three-dimensional object models of the same object as the reference image are previously generated by a three-dimensional shape measurement apparatus in the same way as the above-described representative three-dimensional object model registration, the three-dimensional object models may be used.

The second image generation section 31 generates comparison images that are close in input condition such as the pose and illumination condition to the input image obtained from the image input section 10, for a reference image that is a high precedence candidate in the matching results obtained from the result matching section 60, on the basis of each of the reference three-dimensional object model associated with the reference image obtained from the reference three-dimensional object model storage section 21.

The second image matching section 41 compares the input image obtained from the image input section 10 with each of the comparison images obtained from the second image generation section 31, and calculates each similarity.

General operation of the third embodiment will now be described in detail with reference to FIG. 16 and a flow chart shown in FIG. 17.

At the time of input image matching, steps 100, 101, 102 and 103 shown in FIG. 17 are the same as the operation conducted in the first embodiment shown in FIG. 2.

The second image generation section 31 generates comparison images that are close in input condition such as the pose and illumination condition to the input image obtained from the image input section, for a

reference image that is a high precedence candidate in the matching results obtained from the result matching section 60, on the basis of each of the reference three-dimensional object model associated with the reference image obtained from the reference three-dimensional object model storage section 21 (step 111).

The second image matching section 41 compares the input image obtained from the image input section with each of the comparison images obtained from the second image generation section 31, and calculates each similarity (step 112). Finally, the reference image having high similarity is displayed (step 104).

Effects of the third embodiment which has the configuration and which operates as described above will now be described.

The third embodiment has the configuration in which the reference three-dimensional object model generated by combining representative three-dimensional object models is matched. Even when only one reference image is present every object, therefore, reference images can be retrieved by using the reference three-dimensional object models, with respect to an input image of an object picked up under a different condition concerning the pose and illumination.

The present embodiment has a configuration in which reference images having high similarity are extracted by using a representative three-dimensional object model and then matching of the reference three-dimensional object model with high precedence candidates is conducted. As a result, reference images can be retrieved at high speed.

Operation of the third embodiment will now be described with reference to concrete embodiments.

In the same way as the operation of the first embodiment, representative three-dimensional object models C_j ($j = 1, 2, \ldots, N$) as shown in FIG. 3 are stored in the representative three-dimensional object model storage section 20. Reference images R_i ($i = 1, 2, \ldots, M$) respectively of the objects as shown in FIG. 4 are stored in the reference image storage section 70. A result (similarity) S_{ij} of matching of each of the reference images R_i with the representative three-dimensional object model C_j as shown in FIG. 5 is stored in the reference image matching result storage section 50.

In addition, M reference three-dimensional object models Bi ($i = 1, 2, \ldots, M$) associated with the reference image R_i are previously stored in the reference three-dimensional object model storage section 21 as shown in FIG. 18.

It is supposed that an input image I(u, v) as shown in FIG. 6 is obtained by the image input section 10 at the time of matching of the input image (step 100 in FIG. 16). According to the same processing as the operation in the first embodiment, R_1, R_5 and R_2 are obtained in the cited order as reference images having a high possibility of being an image of the same object as the input image as shown in FIG. 8 by the image generation section 30, the image matching section 40, the result matching section 60, and the result matching section 60 (steps 101, 102 and 103).

With respect to, for example, the reference images R_1, R_5 and R_2 which are three high precedence candidates in the matching result obtained from the result matching section 60, the second image generation section 31 acquires associated reference three-dimensional object models B_1, B_5 and B_2 from the reference three-dimensional object model storage section 21, and generates comparison images $H_{jk}(u, v)$ ($j = 1, 5, 2$, $k = 1, \ldots, L$) which are close in input condition such as the pose and illumination to the input image

obtained from the image input section 10 (step 111). The generation of the comparison images $H_{jk}(u, v)$ is conducted by using a method similar to the step S101. In other words, the second image generation section 31 generates L comparison images $H_{jk}(u, v)$ ($j = 1, 5, 2, k = 1, \dots, L$) which are close in input condition such as the pose and illumination to the input image, with respect to the reference three-dimensional object models B_j ($j = 1, 5, 2$) in the reference three-dimensional object model storage section 21. The second image matching section 41 finds a similarity $S(I, H_{jk})$ between the input image $I(u, v)$ and each comparison image $H_{jk}(u, v)$, and finds a maximum similarity $S_{0j} = \max_k S(I, H_{jk})$ every model (step 112).

The matching results become, for example, as shown in FIG. 19. If $S_{05}>S_{01}>S_{02}$, then R_5, R_1 and R_2 are obtained in the cited order as reference images having a high possibility of being an image of the same object as the input image. Finally, the reference images having high similarities are displayed (step 104).

An image matching system according to a fourth embodiment of the present invention will now be described in detail with reference to FIGS. 20 to 22.

With reference to FIG. 20, an image matching system according to the fourth embodiment of the present invention includes an image input section 10, an image generation section 30, an image matching section 40, a result matching section 60, a second image generation section 31, a second image matching section 41, a result display section 80, a reference image storage section 70, a reference image registration section 75, a representative three-dimensional object model storage section 20, a three-dimensional object model registration section 25, a reference image matching result storage section 50, a reference image matching result

update section 55, a reference three-dimensional object model storage section 21, and a three-dimensional object model generation section 27.

The fourth embodiment has a configuration obtained by adding the reference image registration section 75, the three-dimensional object model registration section 25, the reference image matching result update section 55 and the three-dimensional object model generation section to the configuration of the third embodiment.

As to components in the image matching system according to the fourth embodiment that are the same as those in the third embodiment, description will be omitted. The components added in the present embodiment will be described.

These components nearly operate as described below. The image input section 10, the image generation section 30, the image matching section 40, the result matching section 60, the result display section 80, the reference image storage section 70, the reference image registration section 75, the representative three-dimensional object model storage section 20, the three-dimensional object model registration section 25, and the reference image matching result update section 55 conduct the same processing as the processing conducted in the first embodiment of the present invention shown in FIG. 1 and the second embodiment shown in FIG. 9.

The reference three-dimensional object model storage section 21, the second image generation section 31, and the second image matching section 41 conduct the same processing as the processing conducted in the third embodiment shown in FIG. 16.

When at the time of registration a reference image matching result is registered in the reference image matching result storage section 50 by

the reference image matching result update section 55, the three-dimensional object model generation section 27 generates a reference three-dimensional object model associated with the reference image by combining representative three-dimensional object models in the representative three-dimensional object model storage section 20 on the basis of information of the reference image matching result, and registers the reference three-dimensional object model in the reference three-dimensional object model storage section 21, or updates a reference three-dimensional object model in the reference three-dimensional object model storage section 21.

With respect to the reference images of high precedence candidates in the matching result obtained from the result matching section 60, the second image generation section 31 generates comparison images close in the input condition such as the pose and illumination condition to the input image obtained from the image input section 10, on the basis of each of the reference three-dimensional object models associated with the reference image obtained from the reference three-dimensional object model storage section 21.

The second image matching section 41 compares the input image obtained from the image input section 10 with each of the comparison images obtained from the second image generation section 31, and calculates each similarity.

General operation of the fourth embodiment will now be described in detail with reference to FIG. 20 and flow charts shown in FIGS. 17, 21 and 22.

At the time of matching of the input image, operation conducted at steps 100, 101, 102 and 103 in FIG. 17 is the same as that conducted in the first embodiment shown in FIG. 2.

The second image generation section 31 generates comparison images that are close in input condition such as the pose and illumination condition to the input image obtained from the image input section, for a reference image that is a high precedence candidate in the matching results obtained from the result matching section 60, on the basis of each of the reference three-dimensional object models associated with the reference image obtained from the reference three-dimensional object model storage section 21 (step 111).

The second image matching section 41 compares the input image obtained from the image input section with each of the comparison images obtained from the second image generation section 31, and calculates each similarity (step 112). Finally, the reference image having high similarity is displayed (step 104).

At the time of three-dimensional object model registration, operation conducted at steps 200, 201 and 202 in FIG. 21 is the same as that conducted in the second embodiment shown in FIG. 10. Finally, the three-dimensional object model generation section 27 regenerates a reference three-dimensional object model associated with each reference image by combining representative three-dimensional object models in the representative three-dimensional object model storage section 20 on the basis of information of each reference image matching result in the reference image matching result storage section 50, and registers the reference three-dimensional object model in the reference three-dimensional object model storage section 21, or replaces a stored reference three-dimensional object model by it (step 220).

At the time of reference image registration, operation conducted at steps 210, 211 and 212 in FIG. 22 is the same as that conducted in the

second embodiment shown in FIG. 11. Finally, the three-dimensional object model generation section 27 generates a reference three-dimensional object model associated with the reference image by combining representative three-dimensional object models in the representative three-dimensional object model storage section 20 on the basis of information of the reference image matching result newly registered in the reference image matching result storage section 50, and additionally registers the reference three-dimensional object model in the reference three-dimensional object model storage section 21 (step 221).

Effects of the fourth embodiment which has the configuration and which operates as described above will now be described.

The fourth embodiment has the configuration in which the reference three-dimensional object model generated by combining representative three-dimensional object models is matched. Even when only one reference image is present every object, therefore, reference images can be retrieved by using the reference three-dimensional object models, with respect to an input image of an object picked up under a different condition concerning the pose and illumination.

The present embodiment has a configuration in which reference images having high similarity are extracted by using a representative three-dimensional object model and then matching of the reference three-dimensional object model with high precedence candidates is conducted. As a result, reference images can be retrieved at high speed.

Operation of the fourth embodiment will now be described with reference to concrete embodiments.

In the same way as the operation of the first embodiment, representative three-dimensional object models C_j ($j = 1, 2, \ldots, N$) as shown

in FIG. 3 are stored in the representative three-dimensional object model storage section 20. Reference images R_i (i = 1, 2, ... , M) respectively of the objects as shown in FIG. 4 are stored in the reference image storage section 70. A result (similarity) S_{ij} of matching of each reference image R_i with the representative three-dimensional object model C_j as shown in FIG. 5 is stored in the reference image matching result storage section 50.

In addition, M reference three-dimensional object models Bi (i = 1, 2, ... , M) associated with the reference image R_i are previously stored in the reference three-dimensional object model storage section 21 by the processing conducted at the time of reference image registration, as shown in FIG. 18.

It is supposed that an input image I(u, v) as shown in FIG. 6 is obtained by the image input section 10 at the time of matching of the input image (step 100 in FIG. 16). According to the same processing as the operation in the first embodiment, R_1, R_5 and R_2 are obtained in the cited order as reference images having a high possibility of being an image of the same object as the input image as shown in FIG. 8 by the image generation section 30, the image matching section 40, and the result matching section 60 (steps 101, 102 and 103).

With respect to, for example, the reference images R_1, R_5 and R_2 which are three high precedence candidates in the matching result obtained from the result matching section 60, the second image generation section 31 acquires associated reference three-dimensional object models B_1, B_5 and B_2 from the reference three-dimensional object model storage section 21, and generates comparison images $H_{jk}(u, v)$ (j = 1, 5, 2, k = 1, ... , L) which are close in input condition such as the pose and illumination to the input image obtained from the image input section 10 (step 111). The second image

matching section 41 finds a similarity $S(I, H_{jk})$ between the input image $I(u, v)$ and each comparison image $H_{jk}(u, v)$, and finds a maximum similarity $S_{oj} = \max_k S(I, H_{jk})$ every model (step 112).

The matching results become, for example, as shown in FIG. 19, and R_5, R_1 and R_2 are obtained in the cited order as reference images having a high possibility of being an image of the same object as the input image. Finally, the reference images having high similarity are displayed (step 104).

At the time of three-dimensional object model registration, the three-dimensional object model registration section 25 first registers a new representative three-dimensional object model in the representative three-dimensional object model storage section 20. If N=50 three-dimensional object models are already registered in the representative three-dimensional object model storage section 20, the three-dimensional object model registration section 25 registers a new fifty-first representative three-dimensional object model C_{51} (step 200 in FIG. 21).

Subsequently, by the same processing as the operation in the second embodiment, the reference image matching result update section 55 updates the matching result S_{ij} of each reference image in the reference image matching result storage section 50 (steps 201 and 202).

Finally, the three-dimensional object model generation section 27 regenerates a reference three-dimensional object model B_i associated with each reference image R_i ($i = 1, 2, \ldots, M$) by combining representative three-dimensional object models C_j in the representative three-dimensional object model storage section 20 on the basis of information of each reference image matching result S_{ij} in the reference image matching result storage section 50, and replaces the reference three-dimensional object model already

stored in the reference three-dimensional object model storage section 21 by the reference three-dimensional object model B_i (step 220).

Denoting the shape and texture of the representative three-dimensional object model C_j ($j = 1, 2, \ldots, N$) respectively by $P_{Qj}(x, y, z)$ and $T_{Qj}(R, G, B)$ and denoting the shape and texture of the reference three-dimensional object model B_i ($i = 1, 2, \ldots, M$) respectively by $P_{Qi}(x, y, z)$ and $T_{Qi}(R, G, B)$, the reference three-dimensional object model is calculated according to, for example, the following expressions.

$$P_{Qi}(x, y, z) = \Sigma_j f(S_{ij}) P_{Qj}(x, y, z)$$

$$T_{Qi}(R, G, B) = \Sigma_j f(S_{ij}) T_{Qj}(R, G, B)$$

Here, f is a function that monotonously increases as S_{ij} increases, and that satisfies the relation $\Sigma_j f(S_{ij}) = 1$. As the simplest example, f can be implemented by $f(S_{ij}) = S_{ij}/\Sigma_j S_{ij}$.

At the time of reference image registration, the reference image registration section 75 first registers a new reference image in the reference image storage section 70. If M=100 reference images are already registered in the reference image storage section 70, the reference image registration section 75 registers a new hundred first reference image R_{101} in the reference image storage section 70 (step 210 in FIG. 22).

Subsequently, the reference image matching result update section 55 adds a matching result $S_{101,j}$ associated with the reference image R_{101} to the reference image matching result storage section 50 by conducting the same processing as the operation in the second embodiment (steps 211 and 212).

Finally, the three-dimensional object model generation section 27 generates a reference three-dimensional object model B_{101} associated with the reference image R_{101} by combining representative three-dimensional

object models C_j in the representative three-dimensional object model storage section 20 on the basis of information of the reference image matching result $S_{101,j}$ in the reference image matching result storage section 50, and adds the reference three-dimensional object model B_{101} to the reference three-dimensional object model storage section 21 (step 221).

An image matching system according to a fifth embodiment of the present invention will now be described in detail with reference to FIGS. 23 and 24.

With reference to FIG. 23, an image matching system according to the fifth embodiment of the present invention includes an image input section 10, an image generation section 30, an image matching section 40, a result matching section 60, an image conversion section 36, a partial image matching section 45, a result display section 80, a reference image storage section 70, a representative three-dimensional object model storage section 20, a reference image matching result storage section 50, and a reference three-dimensional object model storage section 21.

These components nearly operate as described below. The image input section 10, the image generation section 30, the image matching section 40, the result matching section 60, the result display section 80, the reference image storage section 70, and the representative three-dimensional object model storage section 20 conduct the same processing as the processing conducted in the first embodiment of the present invention shown in FIG. 1.

With respect to a reference image of a high precedence candidate in the matching result obtained from the result obtained from the result matching section 60, the image conversion section 36 converts the input image and/or the reference image so as to make the input condition (such as

the pose condition) the same on the basis of each reference three-dimensional object model associated with the reference image obtained from the reference three-dimensional object model storage section 21. Thus, the image conversion section 36 generates partial images. The image conversion section 36 is similar to the image conversion section 35 in the second conventional technique shown in FIG. 28.

The partial image matching section 45 conducts comparison on the partial images of the converted input image and reference image obtained from the image conversion section 36, and calculates the similarity. The similarity calculation is conducted in the same way as the step 102.

General operation of the fifth embodiment will now be described in detail with reference to FIG. 23 and a flow chart shown in FIG. 24.

At the time of input image matching, steps 100, 101, 102 and 103 shown in FIG. 24 are the same as the operation conducted in the first embodiment shown in FIG. 2. With respect to a reference image of a high precedence candidate in the matching result obtained from the result obtained from the result matching section 60, the image conversion section 36 converts the input image and/or the reference image so as to make the input condition (such as the pose condition) the same on the basis of each reference three-dimensional object model associated with the reference image obtained from the reference three-dimensional object model storage section 21. Thus, the image conversion section 36 generates partial images (step 121).

The partial image matching section 45 conducts comparison on the partial images of the converted input image and reference image obtained from the image conversion section 36, and calculates the similarity (step

122). Finally, the reference image having high similarity is displayed (step 104).

In the fifth embodiment of the present invention, the image conversion section 36 converts the input image and/or the reference image. Alternatively, the reference image may be previously converted to that under a standard input condition (for example, a standard pose condition) and stored, and the image conversion section 36 may convert the input image to that under the standard input condition (for example, the standard pose condition). By doing so, it becomes unnecessary to convert the reference image each time the matching is conducted, and the matching time can be shortened.

An image matching system according to a sixth embodiment of the present invention will now be described in detail with reference to FIG. 25.

With reference to FIG. 25, an image matching system according to the sixth embodiment of the present invention includes an image input section 10, an image generation section 30, an image matching section 40, a result matching section 60, an image conversion section 36, a partial image matching section 45, a result display section 80, a reference image storage section 70, a reference image registration section 75, a representative three-dimensional object model storage section 20, a three-dimensional object model registration section 25, a reference image matching result storage section 50, a reference image matching result update section 55, a reference three-dimensional object model storage section 21, and a three-dimensional object model generation section 27.

These components nearly operate as described below. The image input section 10, the image generation section 30, the image matching section 40, the result matching section 60, the result display section 80, the

reference image storage section 70, the reference image registration section 75, the representative three-dimensional object model storage section 20, the three-dimensional object model registration section 25, and the reference image matching result update section 55 conduct the same processing as the processing conducted in the first embodiment of the present invention shown in FIG. 1 and the second embodiment shown in FIG. 9.

The reference three-dimensional object model storage section 21 and the three-dimensional object model generation section 27 conduct the same processing as the processing conducted in the third embodiment shown in FIG. 16 and the fourth embodiment of the present invention shown in FIG. 20.

With respect to a reference image of a high precedence candidate in the matching result obtained from the result obtained from the result matching section 60, the image conversion section 36 converts the input image and/or the reference image so as to make the input condition (such as the pose condition) the same on the basis of each reference three-dimensional object model associated with the reference image obtained from the reference three-dimensional object model storage section 21. Thus, the image conversion section 36 generates partial images. The partial image matching section 45 conducts comparison on the partial images of the converted input image and reference image obtained from the image conversion section 36, and calculates the similarity.

General operation of the sixth embodiment will now be described in detail with reference to FIG. 25 and the flow chart shown in FIG. 24.

At the time of input image matching, steps 100, 101, 102 and 103 shown in FIG. 24 are the same as the operation conducted in the first

embodiment shown in FIG. 2. With respect to a reference image of a high precedence candidate in the matching result obtained from the result obtained from the result matching section 60, the image conversion section 36 converts the input image and/or the reference image so as to make the input condition (such as the pose condition) the same on the basis of each reference three-dimensional object model associated with the reference image obtained from the reference three-dimensional object model storage section 21. Thus, the image conversion section 36 generates partial images (step 121).

The partial image matching section 45 conducts comparison on the partial images of the converted input image and reference image obtained from the image conversion section 36, and calculates the similarity (step 122). Finally, the reference image having high similarity is displayed (step 104).

In the sixth embodiment of the present invention, the image conversion section 36 converts the input image and/or the reference image. Alternatively, the reference image may be previously converted to that under a standard input condition (for example, a standard pose condition) and stored, and the image conversion section 36 may convert the input image to that under the standard input condition (for example, the standard pose condition).

When finding the similarity $S(I, G_{jk})$ between the input image $I(u, v)$ and each of the comparison images $G_{jk}(u, v)$ in the first to sixth embodiments of the present invention, the image matching section 40 finds one similarity $S(I, G_{jk})$ on the whole. Alternatively, the image matching section 40 may find similarity $S(I, G'_{jkm})$ every partial region m, and find a maximum similarity $S'_{0jm} = \max_k S(I, G'_{jkm})$ every model.

The partial regions are, for example, regions as shown in FIG. 29. In this case, similarity $S'_{ijm} = \max_k S(R_i, G'_{jkm})$ of each partial region m is stored in the reference image matching result storage section 50 as well. The result matching section 60 calculates a similarity $D_i = \Sigma_m D(S'_{0jm}, S'_{ijm})$ between the matching result S'_{0jm} and the matching result S'_{ijm} of each of the reference images in the reference image matching result storage section 50, and extracts reference images in the descending order of the similarity D_i of the matching result. Furthermore, in the three-dimensional object model generation section 27 in the fourth and sixth embodiments as well, representative three-dimensional object models may be combined every partial region.

In the first to sixth embodiments of the present invention, operation of retrieving an image of the same object as the input image from among a large number of reference images has been described. However, it is also possible to apply the present invention to one-to-one matching for determining whether a specific reference image is an image of the same object as the input image.

It is supposed that a specific reference image is R_1. In the first and second embodiments, the result matching section 60 calculates a similarity $D_1 = D(S_{0j}, S_{1j})$ between the matching result S_{0j} of the input image and the matching result S_{1j} of the reference image R_1. If the similarity D_1 is greater than a threshold, R_1 can be judged to be the same object as the input image. In the third, fourth, fifth and sixth embodiments, the judgment can be made by determining whether the similarity between the input image and a specific reference image in the second image matching section 41 and the partial image matching section 45 is greater than a threshold.

In the image matching system according to the present invention, it is a matter of course that functions of components can be implemented by using hardware. The functions can also be implemented by reading an image matching program 500 into a computer to make the computer execute the functions of components. The image matching program 500 is stored in a recording medium such as a magnetic disk or a semiconductor memory. The computer reads the image matching program 500 from the recording medium.

INDUSTRIAL APPLICABILITY

The present invention can be used for person identification, individual authentication, or the like using an image of a face or the like.